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The present progress report letter covers work performed in the period January, 1964 to December, 1964. In the past year the following reports have been completed:

T. P. Sosnowski	No. 27		"Development of Lasers for Plasma Diagnostics"
H. J. Cook W. B. Johnson M. L. Parsons	32		"Survey of Known Laser Transitions"
Eugene N. Frank	33		"Transport Properties of a Turbulent Lorentz Gas"
Von der Embse	27	I	"On the Characteristics of MHD Induction Generators"
Von der Embse	28	II	"On the Characteristics of MHD Induction Generators"

The two reports by Von der Embse have been completed and are now in the hands of our printing department. These will be mailed to NASA headquarters as soon as available.

The proceedings of the coaxial plasma conference at Case in September, 1962 has appeared as Part 2 of the 1964 November issue of the "Physics of Fluids". Part of the publication cost of these proceedings have been contributed by NASA.

Twenty-five (25) copies of all the above mentioned publications are being mailed under separate cover to NASA headquarters.

Our laser laboratory has been considerably expanded and several laser techniques now are being incorporated in our diagnostic work. Microwave work has been intensified and our facilities to perform intricate experiments with microwave equipment have been appreciably improved, thanks to the accession of excess government property.

In addition to the above reports the following papers have been presented by members of the group.

O. K. Mawardi & I. Greber "Interaction of a Two Dimensional Plasma Beam With a Magnetic Boundary"—Paper P 10, Sixth Annual Meeting Plasma Physics Division, New York, N. Y.

D. A. Meskan & B. S. Tanenbaum "Longitudinal Waves in a Partly Ionized Gas With High Electron Temperature, Paper C 1, Sixth Annual Meeting Plasma Division, New York, N. Y.

W. B. Johnson "Lasers and Laser Spectroscopy" and "Line Shifts of Forbidden Transitions in HeI"—Third Annual Conference Applied Spectroscopy, October, 1964, Cleveland, Ohio.

Reports on specific problems are outlined below:

I. Measurement of Cyclotron Radiation in a Plasma

(A. M. Ferendeci, R. O. Shaffner and A. Alper)

To measure experimentally the cyclotron radiation from a plasma, and check our theoretical work reported previously (Progress Report Letter #4) a wide-band radiometer is being built. To cover the frequency range of 3-11 kmc., a ridge type waveguide and associated components are being built in the machine shop. A 30 mc. I.F. amplifier of very low noise figure and an electromagnet of 1% uniformity over a 30 cm length and magnetic field strength of 1.2 kgauss are already built. After designing and building a ridge-wave guide switch for power comparison, the complete unit will be put together and tested as a whole.

In addition to the measurement and understanding of the cyclotron radiation from a plasma, the wide band radiometer will be an important equipment for further experiments in any kind of radiation measurement or monitoring.

II. Energy Loss of Electrons Traversing a Plasma

(W. B. Johnson, M. R. Smith)

The experiment to measure the energy loss of an electron traversing a plasma is progressing well. In this experiment an electron beam is allowed to traverse a shock wave produced in an electromagnetic shock tube. The energy loss of the beam is measured with a biased Faraday cup and theoretically is in the loss regime where collective effects are dominant over single particle effects.

Previously the electron beam was allowed to pass through thin (1000 Ang) Formvar windows similar to that used in electron microscopy. With the beam currents used window heating destroyed the windows and thus allowed the electron gun and analyzer sections to increase in pressure. ($P_{\text{shock tube}} \sim 1$mm Hg, $P_{\text{electron gun}} \sim 10^{-5}$ mm Hg). This caused many deleterious effects such as ion bombardment of the cathode, arcing and serious beam loss. A high capacity differential pumping system was designed and installed to isolate the gun and analyzer sections from the shock tube. This is now working well. No long term ion bombardment destruction of the cathode has been observed.

The energy analyzer has been improved such that it now had a resolution of approximately ten electron volts corresponding to about a factor of five improvement. Peaks due to the characteristic energy loss of electrons passing through helium are easily observed. By appropriate adjustment of the biasing grid immediately in front of the collector, this detector has been made relatively insensitive to ultraviolet emission or charged particles from the plasma. If necessary this could be improved by gold-plating the present nickel electrodes.

The electron beam has been fired through the high velocity shock wave with little dimunition in intensity due to the shock wave. Electron energies as low as 2000 volts penetrate the plasma with ease. No energy loss measurements have presently been made. Some difficulty has been found in the loss of the electron beam with the firing of the shock tube. The exact mechanism is not presently known. The time constant is such that the experiment is still feasible since the beam intensity falls to about one-half its maximum value at the time of arrival of the shock. The fall-off starts immediately with the firing of the capacitor bank and has a time constant of about 30μ sec.

The recovery time is very long and is very dependent on bank voltage ($\tau \sim 50$ msec., $V = 10$ kv; $\tau \sim 50\mu$ sec, $V = 5$ kv). Both fall and recovery times are pressure independent. No effect of the T-tube firing is observed when the shock tube is blanked off, so that magnetic fields are not a problem ($B \nless 30$ gauss will destroy the beam completely). The best hypothesis at present is that precursor ionization occurs producing ions which move into the electron gun section, are accelerated and momentarily destroy cathode emission. More work will be done on this problem.

The last major portion of this work involves the spectroscopic determination of the plasma properties. Some measurements have been made in the past which indicated that $n_e \sim 10^{16}$ el/cm^3 and $T_e \sim 30{,}000°$K. These techniques are being improved, more detailed calculations of the plasma properties are being made and calibration methods using the carbon arc standard are being worked out.

It is expected that within the next report period that quantitative data will be taken on this problem.

III <u>Magnetically Confined Plasma Beams</u>

(R. Collin, D. Meskan, S. Tanenbaum)

A new reflex discharge source and source magnet were completed and mounted in operating position. In the earlier period of the work reported here this source featured a separately demountable tungsten cathode, increased differential vacuum pumping resistance, and more efficient electrode cooling. The source magnet, with a small mirror configuration, is intended to reduce streaming of the ions to the source backplate, and to produce a reduction in the plasma beam diameter as it passes through the pumping resistance tube.

By changing the size of the differential pumping tube the heating problem was reduced with only a slight decrease in the pressure drop across the tube. The tungsten cathode, later, was discarded in favor of an oxide coated cathode. The electron emission from the oxide cathode is sufficient, but there is a limit of about 8 hours of running time per cathode because of ion bombardment of the oxide. The effect of the oxide impurities in the beam has not been investigated. Ion densities are now up to an acceptable level as far as can be determined by Langmuir probe measurements. However, for very intense discharges, the probes become incandescent and therefore useless. Discharges have been run with as much as 6 amperes of anode current.

Typical operation with the oxide coated cathode is as follows:

Cathode heating current	= 14 amps.
Anode voltage	= 125 volts
Anode current	= 2 amps.
Source pressure	= 3×10^{-2} Torr.
Tube pressure	= 8×10^{-5} Torr.
Ion density	= 3×10^{11} ions cm^{-3}

Our original intention was to attempt the excitation and detection of longitudinal ion waves in the collisionless damping regime. Since the tube pressure attainable with the present pumping system is an order of magnitude too high to insure that the neutral gas particles do not enter into the damping mechanism, we went to the three fluid continuum theory in order to consider the effects of damping by ion-neutral collisions. The early phase of this work resulted in a paper which was given at the Sixth Annual Meeting of the Plasma Physics Division on November 4, 1964.[1]

One of the conclusions drawn was that it would be profitable for us to attempt to verify this theoretical work by using a hot cathode glow discharge before attempting to perform the experiment with the reflex discharge. The reason for this is the uncertainty about drift velocities and radial electric fields in the reflex discharge, and how they will effect the theory.

Experimental work with the hot cathode glow discharge is now in progress.

IV Microwave Ionization and Heating of a Plasma

(A. J. Ferendeci, O. K. Mawardi, R. B. Block, K. Y. Millard)

The ionization and heating experiments by microwave experiments

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[1] Longitudinal Waves in a Partly Ionized Gas With High Electron Temperature. D. A. Meskan and B. S. Tanenbaum. Paper C1, Sixth Annual Meeting of the Plasma Physics Division of the American Physical Society. New York, N. Y. November 4-7, 1964.

are carried out in a cylindrical geometry. An X-Band magnetron of 250 kw peak power of 1μ sec duration is used for the initial breakdown of the gas and an S-Band magnetron of 1 MW peak power of the same duration is used to further ionize and heat the plasma.

To reduce the problems associated with the coupling of high power microwaves into the plasma chamber, the microwave power is transmitted through the center conductor of a coaxial cavity and the inner electrode of the cavity is replaced by a glass cylinder. When there is no ionization, the plasma chamber is a transmission type cylindrical cavity through which microwave power can be transmitted if one of the modes of the cavity is excited. Thus the high fields that are set-up in the cavity break down the gas. Once ionization takes place, the cavity becomes a very lossy wave-guide, with the plasma acting as the lossy outer conductor. Therefore, it is still possible to feed the microwave power into the plasma and further ionize it by ohmic dissipation. The duration of the pulse limits such a heating of the plasma. Preliminary data taken, using a 24 cmc microwave interferometer show average electron densities of greater than 10^{12} pp/cm^3 at 0.1 mm of Hg pressure, a 0.1% or better ionization.

A new cavity of larger dimensions is being constructed such that when the initial breakdown takes place, the chamber becomes a lossy coaxial cavity to a S-Band microwave magnetron. Application of the S-Band, 1 MW, power will heat the plasma through ohmic dissipation. Rough estimates of temperature and density show that the ionization can be increased to 100% at the skin depth. The very high microwave powers that are used in these experiments introduce non-linearities that are ordinarily neglected in small sigual theory. Depth of penetration, various loss mechanisms, rate of ionization, increase in temperature and density have to be recalculated. A laser beam spectrometer will be used to measure the radial variation of density of the plasma such that the depth of penetration of the microwave power, the diffusion rate of high temperature electrons and the density variation with respect to time at any point can be measured.

All necessary components have been built for this phase of the experiment and will be put together in the immediate future.

V. Character of Magneto-hydrodynamic Shock Waves

(W. B. Johnson, G. Spencer)

This experiment is designed to give data on the motion of shock waves through a hot, magnetized plasma. A longitudinal magnetic field (~5000 Gauss) is applied along the axis of a long glass tube. Through this tube a longitudinal, mild pinch discharge is caused to form with the current (~5000 amps) being chosen such as to be well within the stability limits of pinch theory and experiment. Following this pre-ionization discharge a fast capacitor bank ($\tau_{1/4} \sim 1/2\mu$ sec) is fired across a T-tube producing the shock wave. The conditions of the discharge are such that the mean free path will be long enough such that collective shock structure should be observable. Measurements have been made on the afterglow plasma using Kerr cell, image convertor and spectroscopic techniques. All of these indicate that a useful plasma exists out to $\sim 200\mu$ sec with or without a magnetic field. The pre-ionization discharge lasts for about 10-15μ sec and shortly after this the plasma is quite quiescent and shows a normal decay. For the rest of the period. Quantitative spectroscopic techniques are being put into use and should provide reliable data on the pre-ionized plasma conditions and eventually the state of the plasma behind the shock. No measurements have been made on shock velocities to date. The major effort during this period has been placed on determining the character of the preionization discharge. These measurements will be concluded soon and work will start on the shock wave itself.

VI Lasers Investigations of Plasmas

(W. B. Johnson, T. P. Sosnowski, H. J. Cook)

This area of research has been directed towards the investigation of plasma properties. The shift in frequency of the laser cavity due to the presence of a plasma column will be measured and will be related to the electron density.

Constructional techniques for lasers have been developed so that reliable He-Ne tubes can be made. Optical superheterodyne techniques have been studied and the light from two lasers has been mixed on a photo multiplier photocathode. Difference frequencies have been measured and a typical stability of 50 kc/s over several seconds has been found. This corresponds to a shift in frequency of $\sim 10^{12}$ el/cm^3 due to the presence of a plasma column. Better stability is being sought and it is felt that with different mirror mounts, sturdier tables and a different environment that this minimum detectable electron density can be reduced by at least one order of magnitude if not two. A plasma tube suitable for introduction into the cavity has been utilized for quantitative determination of plasma conditions. These show that $T_e \sim 30{,}000°K$ and $n_e \sim 10^{12}$ el/cm^3. Presently improvements in laser frequency stability are being sought.

Analysis has been started on laser experiments to study the frequency spectrum of Thomson scattered laser light. A measurement of the width of the peak centered at the plasma frequency will give an unequivocal measurement of the Landan damping rate. Other experiments being studied are the measurement of the fluctuations in the index of refraction of a hot plasma and the emission of ultraviolet radiation from highly ionized plasma particles. In regard to the latter, a complete survey of existing laser lines has been completed and has shown that there are a number of lines which show promise as a plasma diagnostic tool. It is possible that pulsed plasma discharges such as the θ-pinch machines could be a very strong source of stimulated ultra-violet radiation.

VII Ambipolar Plasma Diffusion

(R. Collin, O. K. Mawardi, G. A. Otteni)

An experiment has been performed to measure the ambipolar diffusion of electrons in a decaying plasma. In this experiment a gas was ionized by a microwave pulse from a magnetron. The diffusion speed of the expanding electron closed was subsequently measured by a Doppler shift technique.

The results obtained showed the plasma to exhibit a number of resonances initial period of in the afterglow. At present a study is being made to determine whether these resonances are entirely of electromagnetic origin or are due to the electrons acoustical resonances (Dattner modes).

The initial electron density in the plasma has been estimated to be about 5×10^{10} per cm^3.

VIII Transport Processes in a Fluctuating Plasma

(O. K. Mawardi, E. N. Frank)

The fields of a turbulent Lorentz gas with average magnetic field are expressed in terms of fluctuating quantities. The equations of conversation of momentum and matter are used along with Maxwell's equations to obtain a Fourier analyzed momentum equation in terms of the fluctuating velocities alone. Non-linear terms are linearized through the use of a dynamic viscosity-like term after Heisberg. The study is then restricted to a semi-compressible plasma. It is found that in general six modes of wave motion are possible; three are modified classical modes and the others are mixed or "turbulent modes" which express the cross correlation between the classical modes present in the turbulence. Numerical results are obtained for the indices of refraction and the mobilities for the various modes. One of the most important results of the analysis is the appearance of an enhanced diffusion above a certain critical value of the magnetic field.

IX MHD Induction Generation

(S. Ostrach)

In order to predict accurately the performance of magnetohydro-dynamic vortex power generators the rotating flow of an electricallyconducting fluid between two coaxial cylinders in a magnetic field must be known in detail. To date most work has neglected the effect of any confining end walls on the flow. The attempts to determine end-wall effects have been limited to studies of rotating flows over a single flat plate. Such studies, however, have little relevance to practical configurations which are completely enclosed so that fluid cannot be drawn into the boundary layer from infinity and the boundary-layer growth on the parallel end plates could, under some conditions, influence the vortex motion.

Thus consideration was given to the more realistic configuration of vortex motion in a region confined by two parallel end plates and by concentric and permeable cylinders through which there is a radial mass flow. The first phase of this work which has been completed gives consideration to the viscous flow in such a region with no magnetohydrodynamic effects, because the viscous fluid solution had not previously been obtained and it is required for the magnetohydrodynamic case. All classes of problems are delineated and special consideration is given to the case where the distance between the end plates is smaller than the radius of the plates so that the boundary-layer blockage effects can be studied. A modified momentum integral solution was obtained which gives the variation of the important parameters such as the boundary-layer thickness and radial velocity with the radius for various values of the imposed radial mass flow. Work is continuing at present to include the magnetohydrodynamic effects.

X MHD Machine With Non-uniform Seeding

(S. Ostrach)

In an attempt to investigate the influence of the non-uniform seeding concentration in a rotating seeded plasma, a model is studied in which the seeding material is regarded as a slightly ionized plasma mixed with a neutral gas. Under the additional assumption of small molar seeding percentage, it is possible to establish the relation between the electric conductivity and the seeding concentration. The problem is represented by a system of nonlinear and tightly coupled differential and algebraic equations. It was decided to treat some steady cases with axisymmetry first. In these cases, only ordinary differential equations are involved. The simplest problem in this group is that of a seeded gas inside a long rotating cylinder with a constant electrical potential difference applied at the ends. It is assumed that some time has elapsed since the beginning of the rotation so that the fluid is now rotating like a solid. The electric connections are assumed to be placed far away from the cylinder so as to preserve axisymmetry. The constant electric field is associated with an axial current in the plasma, the strength of which varies according to the distribution of the seeding material (pressure diffusion). The resulting steady state also dictates the density and temperature distribution of the mixture.

This particular problem has already been formulated and is now ready for the necessary numerical analysis. It is possible that a large class of problems, including some unsteady ones, is numerically tractable. But further endeavor must wait until some experience is gained through the investigation of the simple problem.